COASTAL LAGOONS AND ESTUARIES OF THE GULF OF MEXICO: TOWARD THE ESTABLISHMENT OF ECOLOGICAL INDICATORS

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Coastal lagoons and similar ecosystems are characterized by a continuously changing environment as a result of the hydrological effects caused by the encounter of two water masses of different origin and physico-chemical properties, which in principle limits biodiversity. On the other hand and from another perspective, this encounter results in the presence of various habitats that allow the establishment of organisms, populations and even communities with different requirements. From a spatial point of view, the presence of areas with permanent freshwater influence favors the colonization of organisms originated from continental waters, whereas the constant tidal effect supplies species of marine origin. It is also necessary to emphasize the almost permanent presence of extensive areas where brackish conditions of 10 to 25 ppt present a suitable hydrological environment for the development of typically estuarine organisms and/or those efficiently adapted to it. Thus the average number of fish species per lagoon ranges from 50 to 100, molluscs from 50 to 90, and crustaceans from 40 to 70. Most lagoons are also closely connected to mangrove forests, which represent particularly rich habitats for birds (1,038 species of birds from 86 families are identified in Mexico), reptiles and mammals.

In addition to this, the socio-economic importance of fishing activities carried out in coastal lagoons, particularly in the Gulf of Mexico, is unquestionable. Based on official statistics and on an analysis of the period from 1988 to 1999, it is possible to establish that the majority of fishing in the Mexican Gulf states is represented by river fishing, relative to the total volume of fishing (including deep-sea fishing), and maintains first place for 19 commercial species. All of these species are captured inside the lagoons or in very nearby areas. The abundance of some species is due to the presence of coastal ecosystems. The proportion of river to deep-sea fishing in terms of percentages is: Tamaulipas 91.2, Veracruz 80.4, Tabasco 91.1, Campeche 83.4 and Yucatán 85%. In economic terms, river species are commonly preferred over ocean species (shrimp, lobster, crayfish, etc.) and involve a considerable number of people and related activities.

In summary, the coastal lagoons and estuaries constitute a hydrological effect resulting from the encounter of two types of water and represent the best indicator of the quality of the basin. Thus, knowledge of the main physico-chemical parameters offers an invaluable key to the management of coastal ecosystems and basins. The generation of databases regarding the characteristics of our aquatic ecosystems, both abiotic and biotic, becomes essential for the establishment of indicators for monitoring and control of the health of these systems.

In the present work the results of a considerable number of years of sampling in several lagoons of the Gulf of Mexico are presented in an integrated form for the first time. This allows the establishment of some "normal" values for some abiotic parameters. Unpublished data from several authors are presented below (the sources are specified wherever applicable). A summary of hydrological data is presented with a brief description of each lagoon system, with the objective of collaborating with other investigators.

GENERAL CHARACTERISTICS

The Mexican coastline of the Gulf of Mexico reaches from the states of Tamaulipas to Yucatán. Its total extension is 1,910 km and coastal lagoons cover a surface area of approximately 5,767 km^2. The rivers with highest volume (Grijalva-Usumacinta, Papaloapan) and the largest estuarine ecosystems in the country (Laguna Madre and Laguna de Términos, covering 200,000 and 196,000 hectares, respectively) are located along this coastline. Several economic activities are carried out on the coast, among which river fishing, tourism, ranching, agriculture and oil extraction stand out.

The geological origin of the coast of the Gulf of Mexico is responsible for the presence of extensive coastal plains and continental shelves, which reach from 170 to 269 km in the Campeche Bay and the Yucatán Shelf. Except for the northern portion of Tamaulipas and part of the Yucatán Peninsula, evaporation and precipitation are similar, in addition to the important freshwater contributions from numerous rivers, which promote a tendency to estuarine characteristics of the water bodies and oligohaline conditions in some cases, such as the Centla marshes in Tabasco.

SOME BIOLOGICAL CHARACTERISTICS OF THE LAGOONS AND ESTUARIES OF THE GULF OF MEXICO

From the biological point of view, the Gulf's coastal lagoons (Figure 12.1) present individual characteristics and diversity promoted by hydrological factors and by the rate of water exchange, as well as by the dominant influence, whether it is marine or fresh water, as determined by seasonality (Nixon 1981; Knoppers *et al.* 1991; Knoppers and Kjerve 1999; Alber 2002). However, there are some components that are shared, such as the presence of mangrove forests composed of well-known species (*Rhizophora mangle*, *Laguncularia racemosa*, *Avicennia germinans* and *Conocarpus erectus*), although the four species do not always coexist. Seagrasses are also strongly represented in the majority of coastal environments, especially towards the Yucatán. The phytoplankton is dominated by diatoms, and copepods are predominant in the zooplankton. *Acartia tonsa* is a frequent species in all of them; similarly, the presence of fish such as *Mugil cephalus* and *Mugil curema* is common. The number of crustacean, mollusc and fish species varies from one lagoon to another, and frequently this is due to particular characteristics of the environment, although in certain occasions it can be explained by the sampling method used by the researcher. Table 12.1 presents a summarized inventory of the Gulf of Mexico lagoons.

LAGUNA MADRE

This is the largest coastal lagoon in Mexico with a surface area of 200,000 ha. In high salinity areas the surrounding vegetation is dominated by the *Suaeda nigra-Salicornia ambigua* association; the latter is frequently replaced by *Batis maritima* and, on occasions, by a halophyte cover of *Distichlis spicata* and *Monanthochloe littoralis*. On the slightly better drained plains *Spartina spartinae* and *Spartina densiflora* settle over such associations. Ichthyoplankton is represented by 17 families, 25 genera and 29 species. The most abundant are the families Engraulidae, Gobiidae and Sparidae (Ocaña and Sánchez 1991). The caridea are represented by

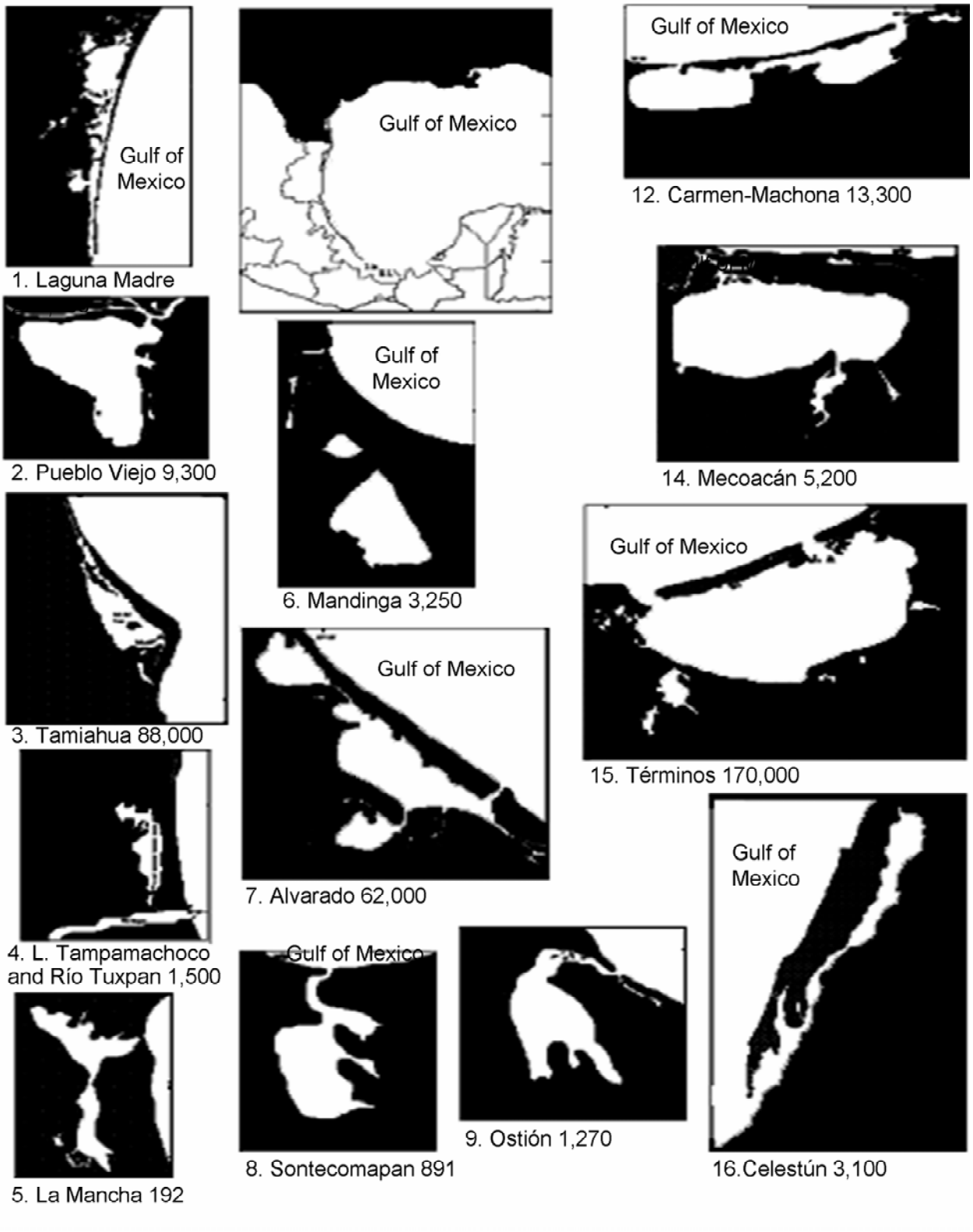

Figure 12.1. Main coastal lagoons of the Gulf of Mexico.

Table 12.1. Summarized inventory of lagoons in the Gulf of Mexico.

	Ha	N. Lat.	W. Long.		Ha	N. Lat.	W Long.
Veracruz				**Tamaulipas**			
Lag. Pueblo Viejo	9,300	22° 13'	97° 57'	Lag. Madre	200,000	25° 48'	97° 54'
		22° 05'	97° 50'	Lag. El Catán		24° 01'	97° 23'
Lag. Tamiahua	88,000	22° 06'	97° 46'	Lag. Morales	3,200	23° 46'	97° 47'
		21° 15'	97° 23'	Lag. San Andrés	9,700	22° 47'	97° 54'
Lag. Tampamachoco	1,500	21° 02'	97° 22'			22° 32'	97° 41'
		20° 18'	97° 19'	Lag. El Chairel	4,200	22° 10'	97° 51'
Estuario Tecolutla		20° 29'	97° 04'	Est. Río Pánuco		22° 28'	98° 38'
		20° 27'	97° 00'	***Total # of ecosystems***[a]	**19**		
Lag. Casitas-Nautla		20° 15'	97° 00'				
		20° 06'	96° 00'	**Tabasco**			
Lag. Grande	2,250	20° 06	96° 41'	Lag. El Carmen	8,800	18° 18'	93° 53'
		20° 02'	96° 38'	Lag. La Machona	6,500	18° 14'	93° 45'
Lag. San Agustín	172	19° 56'	96° 35'	Lag. Tupilco	800	18° 26'	93° 27'
		19° 55'	96° 30'			18° 24'	93° 25'
Lag. Verde	110	19° 43'	96° 25'	Lag. Mecoacán	5,200	18° 28'	93° 14'
Lag. El Llano	2,360	19° 36'	96° 21'			18° 16'	93° 04'
Lag. El Farallón	800	19°38'	96° 24'	Pantanos de Centla	300,000	18° 39'	92° 47'
Lag. La Mancha	192	19° 42'	96° 32'			17° 57'	92° 06'
		19° 34'	96° 27'	***Total # of ecosystems***[a]	**37**		
Est. La Antigua	270	19°29'	96° 18'				
Lag. Mandinga	3,250	19° 06'	96° 06'	**Campeche**			
		19° 00'	96° 02'	Lag. Atasta	3,600	18° 40'	92° 14'
Lag. Alvarado	6,200	18° 59'	95° 57'	Lag. Pom	5,200	18° 33'	92° 01'
Lag. Camaronera	3,900	18° 43'	95° 42'	Lag. deTérminos	170,000	19° 00'	92° 00'
Lag. Sontecomapan	891	18° 34'	95° 04'			18° 20'	91° 10'
		18° 30'	95° 00'	***Total # of ecosystems***[a]	**12**		
Lag. del Ostión	1,270	18° 15'	94° 42'				
		18° 07'	94° 37'	**Yucatán**			
Est. Río Coatzacoalcos	900	18° 10'	94° 25'	Lag. Celestún	3,100	20° 59'	90° 28'
Est. Río Tonalá		18° 14'	94° 08'			20° 46'	90° 19'
Total # of ecosystems[a]	**101**			E. Yucalpetén		21° 19'	89° 47'
				Lag. Chelém		21° 15'	89° 40'
				Dzilam de Bravo	400	21° 22'	88° 59'
				Ría Lagartos	10,000	21° 34'	88° 15'
						21° 32'	87° 35'
				Total # of ecosystems[a]	**5**		

TOTAL GULF ECOSYSTEMS: 174

[a] The "total # of ecosystems" includes the total number of associated lagoons and equivalent water bodies

six genera and nine species, with predominance of *Hippolyte pleurocantharus* and *Tozeuma carolinense* (Barba *et al.* 1993, in Castañeda and Contreras 2001). Thirty-eight species of molluscs were identified. The dominant faunistic group in the lagoon is composed by the pelecypods *Mulinia lateralis*, *Anomalocardia auberiana* and the gastropod *Acteon punctostriatus*, which are very abundant (García-Cubas 1978). Seventy-eight species of fish are reported, of which the following stand out: *Lagodon rhomboides*, *Anchoa mitchilli*, *Leiostomus xanthurus*, *Membras martinica*, *Micropogonias undulatus*, *Gobiosoma robustum*, *Hyporhamphus unifasciatus* and *Eucinostomus argenteus* (Barba *et al.* 1991, in Castañeda and Contreras 2001; Gómez and Contreras 1991). The waterfowl is composed of a total of 11,430 individuals and 27 species, of which six are permanent residents, 19 are overwintering species and two are transient migratory species. It should be mentioned that 86% of the registered individuals have migratory status. The main observed trend was for the number of species and individuals in the northern and central areas, with 23 and 8,734, and 24 and 1,518, respectively. The southern area exhibited the lowest values, with 13 species and 1,178 individuals, of which the following stood out: *Calidris mauri*, *Calidris alpina*, *Charadrius montanus*, *Haematopus palliatus*, *Himantopus mexicanus*, *Charadrius alexandrinus* and *Charadrius wilsonia* (González *et al.* 2001). The hydrological data of the Laguna Madre is presented in Table 12.2.

Table 12.2. Hydrology of Laguna Madre de Tamaulipas

Parameter	Min	Max	Mean	Stand. Dev.	n
Salinity (ppt)	33.5	63.0	41.2	5.2	52
Temperature (°C)	14.6	28.0	25.9	5.3	52
Dissolved Oxygen (ml/L)	4.0	9.2	5.0	1.4	51
Dissolved Oxygen (% saturation)	72.0	164.0	106.0	24.6	51
pH	7.9	9.4	8.9	4.4	28
Chlorophyll *a* (mg m^{-3})	0.01	54.7	5.3	13.2	39
Primary Productiv. (mg C m^{-3} hr^{-1})	2.1	603.1	81.0	158.9	33
N-NH_4 (μg/L)	0.8	20.7	3.6	4.1	51
N-NO_3+NO_2 (μg/L)	0.4	5.9	2.4	1.4	52
Total N (μg/L)	2.9	22.9	6.8	4.1	51
NH_4/Total N	20.7	97.8	62.0	19.5	51
P-PO_4 (μg/L)	0.1	7.6	2.1	2.3	52
Total P (μg/L)	0.9	29.5	6.9	7.6	43
Organic P (μg/L)	0.0	27.7	1.4	7.5	43
N:P Ratio	0.5	18.8	2.7	3.6	50
Trophic index	25.2	69.8	48.2	10.4	36
C/Chl (mg C m^{-3} hr^{-1}/mg chl. m^{-3})	0.3	63.0	7.3	19.0	18

LAGUNA MORALES

There is no published information.

LAGUNA SAN ANDRÉS

The list of molluscs is composed of 35 gastropods and 25 bivalves. The species with the greatest relative abundance and distribution in the system are: *Diastoma varium, A. auberiana, Cerithidea pliculosa, M. lateralis, Acteocina canaliculata, Rangia (Rangianella) flexuosa, Odostomia weberi, Laevicardium mortoni, N. virginea* and *A. punctostriatus* (García-Cubas *et al.* 1990a).

RÍO PANUCO ESTUARY

The estuary is associated with the lagoons El Chairel, Pueblo Viejo, Cerro Pez, Dulce, Tortugas, Chila Marlano, Los Moros, Quimin Camalote, Herradura and Tancoco. The hydrological basin covers approximately 107,200 km^2 and is 510 km long. Its source is in the state of Mexico, and it runs from southwest to northeast through the states of México, Hidalgo, Puebla, Tlaxcala, Querétaro, Guanajuato and Veracruz. In all these states it is fed by flows that contribute to its formation.

Laguna Pueblo Viejo

Thirty-five species of molluscs (Reguero and García-Cubas 1992) and 67 of fish have been identified. The predominant species were: *Bairdiella chrysoura, A. mitchilli, Cathorops melanopus, Mugil curema, Opsanus beta, Brevoortia patronus, Ariopsis felis, Bairdiella ronchus* and *Dorosoma cepedianum* (Kobelkowsky 1991). The lagoon has suffered from the influence of the Río Pánuco and the industrial and domestic waste carried by its waters, with a sufficiently strong impact to considerably affect the oyster production. Table 12.3 presents the hydrological data for this lagoon.

LAGUNA DE TAMIAHUA

Ruppia maritima dominates the submerged vegetation, but there is significant presence of *Halodule beaudetti*. In terms of ichthyoplankton 15 families and 26 species were observed, of which *A. mitchilli, B. chryosura, C. nebulosus, G. bosci, M. gulosus, M. vagrans, Achirus lineatus, S. louisianae* and *S. scovelli* stand out (Barba and Sánchez 1981). The species of zooplankton detected include: *A. tonsa, Labidocera aestiva, Oithona plumifera, Corycaeus flaccus, Corycaeus speciosus,* and *Caligus sp.* (Alvarez and Gómez 1993). Sixty-two species of molluscs were identified, including the gastropods *Littoridina (Texadina) sphinctostoma* and *Retusa canaliculata,* and the bivalves *R. flexuosa* and *M. lateralis* (Bravo *et al.* 1987, in Castañeda and Contreras 2001), 26 of crustaceans (Raz-Guzmán *et al.* 1991), 64 of polychaetes, with predominance of *Spio pettibonae, Pectinaria gouldi, Capitella capitata, Malacoceros vanderhorsti, Glycinde solitaria, Mediomastus californiensis* and *Sigambra bassi* (Castañeda and Contreras 2001), and 56 of other organisms. One hundred and twenty species of fish are known, the foremost being: *B. chrysoura, A. mitchilli, Anchoa hepsetus, Cynoscion nebulosus, Oligoplites saurus, Diapterus olisthostomus, Menidia beryllina, H. unifasciatus, Membras*

Table 12.3. Hydrology of Laguna Pueblo Viejo, Veracruz (1995).

Parameter	Min	Max	Mean	Stand. Dev.	n
Salinity (ppt)	0.7	38.1	13.4	7.7	34
Temperature (°C)	19.0	34.0	28.0	4.1	35
Dissolved Oxygen (ml/L)	3.5	9.2	7.2	1.5	35
Dissolved Oxygen (% saturation)	73.0	235.0	127.0	33.0	34
pH	7.8	8.8	8.1	0.2	32
Chlorophyll *a* (mg m^{-3})	0.01	64.1	5.9	16.3	21
Primary Productiv. (mg C m^{-3} hr^{-1})	2.1	552.1	127.6	237.3	12
N-NH_4 (μg/L)	1.3	31.3	5.6	7.1	31
N-NO_3+NO_2 (μg/L)	0.3	18.0	3.6	3.3	34
Total N (μg/L)	3.1	38.0	10.9	7.8	32
NH_4/Total N	12.4	91.5	66.6	25.5	31
P-PO_4 (μg/L)	1.0	9.1	2.3	1.8	34
Total P (μg/L)	2.5	16.1	5.2	2.6	33
Organic P (μg/L)	0.4	14.3	2.5	2.8	31
N:P Ratio	0.9	15.7	5.2	4.6	31
Trophic index	30.0	71.4	49.7	11.5	16
C/Chl (mg C m^{-3} hr^{-1}/mg chl. m^{-3})	0.0	87.6	34.6	29.8	10

vagrans, *A. felis*, *Strongylura notata*, *M. curema* and *Sphoeroides greeleyi*. Based on the results obtained to date, six new species have been included on the list of ichthyofauna from previous studies: *Lutjanus griseus*, *Porichthys porosissimus*, *Fundulus grandis*, *Menticirrhus litoralis*, *Harengula pensacolae* and *Lutjanus apodus* (de la Cruz *et al.* 1985). The presence of coliform bacteria related to riverside human settlements is evident (Barrera 1995). Table 12.4 presents the hydrological data for Laguna de Tamiahua.

LAGUNA DE TAMPAMACHOCO

A total of 23 species of macroalgae were identified: 9 Chlorophyceae, 2 Phaeophyceae and 12 Rhodophyceae. The algal richness per area is relatively high (60 to 100 times) relative to other larger coastal lagoons (Laguna Madre and Tamiahua with 29 and 22 species, respectively) (Dreckmann and Pérez 1994). The copepods *Acartia paracalanus* and *Temora* sp. are predominant in the zooplankton. Lagoon environments characteristic of certain zooplankters such as the jellyfish *Blackfordia virginica*, *Bougainvillia niobe*, *Aurelia aurita* and *Dactylometra* sp., and the ctenophors *Beröe ovata* and *Mnemiopsis leidyi*, among others, were also reported. Other identified groups include 66 species of molluscs, of which the following stand out: *C. pliculosa*, *A. canaliculata*, *M. lateralis*, *L. sphinctostoma*, *Mytilopsis leucophaeata* and *Neritina*

Table 12.4. Hydrology of Laguna Tamiahua, Veracruz (1996)

Parameter	Min	Max	Mean	Stand. Dev.	n
Salinity (ppt)	14.4	37.5	18.1	6.2	52
Temperature (°C)	23.0	34.0	29.5	2.8	52
Dissolved Oxygen (ml/L)	2.1	8.1	6.0	1.6	51
Dissolved Oxygen (% saturation)	43.0	155.0	124.0	31.7	51
pH	7.5	9.4	8.4	2.6	47
Chlorophyll *a* (mg m^{-3})	0.02	64.1	10.1	14.8	38
Primary Productiv. (mg C m^{-3} hr^{-1})	7.1	360.6	21.3	52.1	15
N-NH_4 (μg/L)	0.7	32.0	6.7	10.1	48
N-NO_3+NO_2 (μg/L)	0.7	12.3	2.6	2.3	52
Total N (μg/L)	1.5	35.2	10.3	10.1	48
NH_4/Total N	7.4	97.1	74.0	26.5	48
P-PO_4 (μg/L)	0.1	7.0	2.5	1.8	51
Total P (μg/L)	1.9	9.3	4.3	1.9	49
Organic P (μg/L)	0.1	5.0	1.6	1.2	49
N:P Ratio	0.5	35.3	3.2	8.5	40
Trophic index	3.0	71.4	53.5	17.5	36
C/Chl (mg C m^{-3} hr^{-1}/mg chl. m^{-3})	0.5	17.7	1.2	6.4	12

reclivata (Reguero *et al.* 1991); 14 of crustaceans (Chávez 1967, in Castañeda and Contreras 2001) and 53 of other organisms (Méndez 1989). The most common fish species are *Diapterus auratus*, *Bairdiella ronchus*, *Citharichthys spilopterus*, *Arius melanopus*, *Gobionellus hastatus*, *Centropomus parallelus*, *Centropomus undecimales*, *M. curema*, *Dormitator maculatus* and *Syngnathus scovelli* (Kobelkowsky 1991). The combined record of 171 species establishes the Tuxpan-Tampamachoco region as the second most important estuarine-lagoon area in the Gulf of Mexico regarding species richness, after Laguna de Términos in Campeche. Eighteen new records have been made in the area, including the presence of a new family (Cichlidae) with an autochthonous species, and 10 new genera of families already reported (Pérez *et al.* 1994). It receives considerable wastewater discharges and the bacteria associated with coliforms, such as *Shigella*, *Salmonella* and *Vibrium*, are common. Its hydrology is shown in Table 12.5.

TUXPAN ESTUARY

This estuary is formed by the merging of the Vinazco and Pantepec rivers, which flow down the Sierra Madre Oriental. It runs from west to east along the coastal plain of the Gulf of Mexico, receiving the Mequetla and de Cañas streams from the south, the Río Buenavista from the Sierra de Otontepec, and the Arroyo Hondo and the waters of the Laguna de Tampamachoco from the north. It empties into the Gulf of Mexico, forming the Tuxpan barrier island. The estuary is navigable for 67 km. It exhibits a typical estuarine circulation most of the year (Contreras 1983).

Table 12.5. Hydrology of Laguna Tampamachoco, Veracruz.

Parameter	1980					1990				
	Min	Max	Mean	St. D.	n	Min	Max	Mean	St. D.	n
Salinity (ppt)	28.6	38.5	34.0	8.0	36	8.9	44.5	29.4	10.3	113
Temperature (°C)	20.7	34.0	28.6	7.2	36	17.0	34.5	29.6	6.3	117
Dissolved Oxygen (ml/L)	2.2	6.6	4.1	1.5	36	1.8	9.0	4.5	1.9	114
Dissolved Oxygen (% saturation)	42.0	155.0	85.5	35.1	36	11.0	196.0	100.0	46.9	100
pH	7.8	8.4	8.0	4.1	17	6.7	9.3	8.1	1.9	114
Chlorophyll *a* (mg m^{-3})	0.3	16.1	4.8	4.2	27	0.1	90.4	12.6	19.3	104
Primary Productiv. (mg C m^{-3} hr^{-1})						9.4	527.0	104.0	115.9	88
$N\text{-}NH_4$ (µg/L)	0.1	15.1	4.5	3.7	31	0.0	39.4	5.3	8.4	119
$N\text{-}NO_3+NO_2$ (µg/L)	0.2	4.5	0.6	0.8	32	0.4	55.6	2.7	7.5	120
Total N (µg/L)	0.5	15.6	5.7	3.9	29	0.8	74.7	8.4	11.9	119
NH_4/Total N	14.9	96.9	87.4	22.8	29	1.3	93.4	63.4	27.3	119
$P\text{-}PO_4$ (µg/L)	0.1	1.4	0.6	0.4	33	0.1	37.2	6.9	8.3	118
Total P (µg/L)	0.8	9.9	1.6	2.7	32	0.3	99.6	13.8	14.8	104
Organic P (µg/L)	0.2	8.5	1.0	2.4	32	0.0	63.1	3.6	8.5	104
N:P Ratio	1.0	26.1	10.0	6.9	25	0.1	36.3	1.7	9.4	113
Trophic index	18.8	57.8	45.9	9.6	27	1.2	74.8	55.4	15.4	93
C/Chl (mg C m^{-3} hr^{-1}/mg chl. m^{-3})	-	-	-	-	-	0.5	75.5	7.1	14.8	60

TECOLUTLA ESTUARY

The estuary originates in the Sierra de Puebla, and is formed by the confluence of the Necaxa, Axacal, Cempoala and San Pedro rivers. The estuary is fed by the Chichicatzapa stream near its outlet, forming the Tecolutla barrier island. The most common and abundant species of polychaetes were *Polyphthalmus* sp., *M. californiensis* and *Cossura candida*. Temporary ichthyofauna inhabitants of the estuarine component were: *A. mitchilli mitchilli*, *M. cephalus*, *M. curema*, *Centropomus undecimalis*, *Bagre marinus* and *Erotelis smaragdus*; the only permanent inhabitants of the estuarine component were *G. hastatus*, and euryhaline species from the marine component were *D. olisthostomus*, *Arius felis*, *Oostethus lineatus*, *Strongylura marina*, *Caranx hippos*, *Gobiomorus dormitator* and *O. beta* (Rodríguez 1990). The total number of fish species was 57 (Martínez 1993). One hundred and six species of birds from 77 genera and 39 families belonging to 15 orders are reported (de Sucre *et al.* 1985, in Castañeda and Contreras 2001; Moreno 1986). The hydrology of this estuary is presented in Table 12.6.

CASITAS-NAUTLA ESTUARY

The Río Nautla maintains a free connection with the open sea through an opening in the Nautla barrier island, which is a strip of land in front of the coastline. The mouth of the river communicates simultaneously with the Tres Bocas de Casitas marsh. The Río Nautla originates in the Sierra de Teziutlán where it is known as the Altotonga or Alseseca. It runs from south to

Table 12.6. Hydrology of the Tuxpan Estuary, Veracruz (1980).

Parameter	Min	Max	Mean	Stand. Dev.	n
Salinity (ppt)	1.5	36.0	16.6	8.3	68
Temperature (°C)	16.5	32.5	27.7	4.4	82
Dissolved Oxygen (ml/L)	2.3	7.6	5.3	1.0	61
Dissolved Oxygen (% saturation)	45.0	145.0	101.5	19.8	54
pH	7.3	8.9	8.2	0.4	33
Chlorophyll *a* (mg m^{-3})	0.4	76.5	4.7	15.7	46
$N\text{-}NH_4$ (μg/L)	0.2	16.0	3.4	4.2	42
$N\text{-}NO_3+NO_2$ (μg/L)	0.1	15.9	0.5	3.7	41
Total N (μg/L)	0.7	27.6	3.5	7.3	34
NH_4/Total N	10.2	97.5	80.0	27.6	34
$P\text{-}PO_4$ (μg/L)	0.1	1.5	0.3	0.4	41
Total P (μg/L)	0.2	7.9	1.5	2.0	31
Organic P (μg/L)	0.01	6.7	1.1	1.6	31
N:P Ratio	1.3	96.5	8.3	19.0	33
Trophic index	21.6	73.1	45.8	10.4	46

north and is fed from the right by the Río Bobos, which flows down from the Cofre de Perote. It turns to the northeast and is fed by the Río Quila. Once it reaches the coastal plain, it is fed from the left by the Río María Martinez de la Torre and from the right by the Río Chapachapa. The ichthyplankton is dominated by *Syngnathus* sp., *A. mitchilli*, the family Engraulidae, *Hypsoblennius hentzi*, *Cynoscion* sp., *Gobiosoma* sp., *Haemulon plumieri*, *Gobionellus boleosoma*, *B. chrysoura*, *Trinechtes maculatus* and *O. chrysoptera*. Thirty-four species of fish have been identified, of which the most abundant are *A. melanopus*, *M. curema* and *Polydactilus octonemus*, in addition to 17 species of crustaceans (Franco *et al.* 1982).

LAGUNA GRANDE

A total of 37 species of molluscs has been identified, of which the most abundant species were *L. sphinctostoma*, *Cyrenoida floridina*, *Neritina (Vitta) virginea* (García-Cubas *et al.* 1992), and 36 species of crustaceans, of which *Macrobrachium acanthurus*, *Penaeus setiferus*, *Callinectes exasperatus*, *Callinectes danae*, *Cardisoma guanhumi*, *Octonema cuadrata*, *Pilumnus pannosus* and *Uca mordax* were frequent (González *et al.* 1985). There are 39 species of fish, with predominance of *Bathygobius soporator*, *D. maculatus*, *Eleotris abacurus*, *Eleotris pisonis*, *Eleotris smaragdus*, *Gobioides broussonneti*, *G. boleosoma*, *G. hastatus* and *G. dormitator* (de la Cruz *et al.* 1985).

LAGUNA SAN AGUSTÍN

Thirty-three species of fish have been identified. The most represented were *A. mitchilli* and *Diapterus rhombeus* (Sánchez 1989).

LAGUNA VERDE

There is no published information.

EL LLANO (CAMARÓN)

Twenty-six species of crustaceans were identified (Oliva 1991) and 46 of fish, the most abundant being: *A. mitchilli*, *G. boleosoma*, *D. olisthostomus*, *G. hastatus*, *Eucinostomus melanopterus* and *Poecilia latipunctata* (Morales 1984).

EL FARALLÓN

Among the ichthyofauna the cichlids *Tilapia rendalli* (redbreast tilapia) and *Cichlasoma gadovii* ("guapote" in Spanish), the characid *Astyanax fasciatus* (blind cave fish), the poecilid *P. latipunctata* (broadspotted molly) and the clupeid *Dorosoma petenense* (threadfin shad) are predominant (Serrano and Juárez 1988).

LAGUNA LA MANCHA

The following species were identified in the zooplankton: *Paracalanus aculeatus*, *Pseudodiaptomus coronatus*, *Temora turbinata*, *Centropages furcatus*, *L. aestiva*, *Acartia lilljeborgii*, *A. tonsa*, *Tortanus setacaudatus*, *Euterpina acutifrons*, *Diosaccus tenuicornis*, *Corycaeus lautus*, *Ergasilus* sp. and *Cymbasoma* sp.

The most numerous group was of calanoid copepods, with *A. tonsa* and *T. setacaudatus* as the dominant species (Alvarez 1988, in Castañeda and Contreras 2001). Forty-four species of molluscs and 24 of other organisms have been detected (Reyes 1986). Molluscs of commercial importance in the area are: *Crassostrea virginica*, *Isognomon alatus*, *Melongena melongena*, *M. leucophaeata*, *Ischadium recurvum* and various gastropods characteristic of mesohaline lagoon areas (5 to 18 ppt); *M. melongena*, *C. pliculosa*, *M. lateralis* and some other species characteristic of polyhaline lagoon areas (18 to 30 ppt); and *Odostomia impresa* and *Nassarius vibex* which are species characteristic of polyhaline or euryhaline lagoon areas (25 to 40 ppt) (Flores *et al.* 1988). Forty three species of fish were identified, and the ichthyofauna was typified by *E. melanopterus*, *G. boleosoma*, and *B. soporator* (Ramírez *et al.* 1993). The hydrology of the Laguna La Mancha is presented in Table 12.7.

LA ANTIGUA.

The river originates on the eastern slope of the Sierra Madre Oriental to the north of Pico de Orizaba, with the name of Río Chichiquila. It runs down a deep ravine, being joined by several rivers that flow down from the Cofre de Perote and changing its name to Río Jacomulco or Pescados. It continues from west to east, receiving the rivers Santa María, Paso de Ovejas and San Juan from the right and emptying into the Gulf of Mexico, where it forms the La Antigua barrier island. In the estuary there occur: *C. guanhumi*, *Gecarcinus lateralis*, *Uca pugilator*, *Sesarma cinereum* and *Ocypode* sp., of which *S. cinereum* is the most common (Díaz and Chávez 1987). Fiddler crabs are represented by three species and a subspecies of *Uca*: *U. rapax*, *U. marguerita*, *U. spinicarpa* and *U. (Minuca) vocator vocator* (Díaz 1992). Thirty-seven

Table 12.7. Hydrology of the Laguna La Mancha, Veracruz (2002).

Parameter	Min	Max	Mean	Stand. Dev.	n
Salinity (ppt)	1.0	35.0	19.7	9.4	84
Temperature (°C)	21.0	36.5	28.7	3.6	84
Dissolved Oxygen (ml/L)	0.3	5.8	3.4	1.4	84
Dissolved Oxygen (% saturation)	6.6	128.0	70.5	30.2	84
pH	6.8	8.1	7.5	0.4	60
Chlorophyll *a* (mg m^{-3})	0.01	38.7	3.9	7.3	82
Primary Productiv. (mg C m^{-3} hr^{-1})	5.9	313.4	45.3	79.0	68
$N\text{-}NH_4$ (µg/L)	1.4	44.6	7.0	6.3	72
$N\text{-}NO_3+NO_2$ (µg/L)	0.0	19.0	1.5	2.6	71
Total N (µg/L)	2.5	50.0	8.6	6.9	72
NH_4/Total N	6.9	100.0	84.2	19.5	72
$P\text{-}PO_4$ (µg/L)	2.3	27.4	5.7	5.7	71
N:P Ratio	0.2	10.8	1.3	1.6	71
Trophic index	23.3	66.4	48.4	9.0	68
C/Chl (mg C m^{-3} hr^{-1}/mg chl. m^{-3})	0.8	88.7	10.6	22.2	52

species of fish have been identified, of which *D. rhombeus, Caranx latus, M. curema, Cichlasoma ellioti* and *A. melanopus* stand out (Cubillas *et al.* 1987, in Castañeda and Contreras 2001). The hydrology of this estuary is presented in Table 12.8.

LAGUNA MANDINGA

This lagoon is associated with the Río Jamapa, which originates from thawing ice and snow from the Pico de Orizaba and travels 150 km. It runs from west to east, receives several tributaries of the Huatusco, Cotaxtla and Totolapan rivers, and empties into the Gulf of Mexico at the place known as Boca del Río near to the city of Veracruz. Thirty-two species of molluscs (Reguero and García-Cubas 1993), 40 species of fish, 185 of birds and 25 of other organisms have been identified. The most common fish species are *D. olisthostomus*, *D. rhombeus*, *A. melanopus*, *M. curema*, *A. hepsetus*, *A. felis* and *A. mitchilli* (de la Cruz *et al.* 1985). Eighteen orders, 42 families, 131 genera and 185 species of birds were reported, approximately 60 of which inhabit the aquatic and subaquatic vegetation. The remainder corresponds to species common to mangroves and other types of vegetation (Alafita and Martínez 1993, in Castañeda and Contreras 2001). The hydrology of this lagoon is presented in Table 12.9.

LAGUNA ALVARADO

The lagoon is formed mainly by the Laguna Alvarado itself and Buen País, Camaronera and Tlalixcoyan lagoons, although it exhibits a large number of other small water bodies and flooded areas. The lagoon system is associated with the Río Papaloapan, whose basin covers an approximate area of 39,189 km^2, extends through the states of Oaxaca, Puebla and Veracruz and travels a total of 445 km. The submerged vegetation is basically *R. maritima*, which forms small seagrass beds near Barra Vieja. Sixty-two species of molluscs have been identified, of which *R.*

Table 12.8. Hydrology of the La Antigüa Estuary, Veracruz (1982).

Parameter	Min	Max	Mean	Stand. Dev.	n
Temperature (°C)	28.2	29.5	29.0	0.5	8
Dissolved Oxygen (ml/L)	2.9	5.0	3.5	0.8	8
pH	5.9	7.1	6.2	0.6	6
Chlorophyll *a* (mg m^{-3})	0.00	18.7	6.7	5.7	19
Primary Productiv. (mg C m^{-3} hr^{-1})	3.2	16.4	7.4	3.4	19
$N\text{-}NH_4$ (µg/L)	1.1	49.6	10.6	12.3	19
$N\text{-}NO_3+NO_2$ (µg/L)	7.1	56.5	19.2	11.2	19
Total N (µg/L)	11.6	90.8	47.9	26.2	19
NH_4/Total N	1.8	4.7	4.0	0.9	8
$P\text{-}PO_4$ (µg/L)	1.8	3.0	2.7	0.4	8
Total P (µg/L)	4.8	13.4	7.6	2.7	8
Trophic index	15.4	59.3	49.6	10.5	18

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Table 12.9. Hydrology of Laguna Mandinga, Veracruz (1996)

Parameter	Min	Max	Mean	Stand. Dev.	n
Salinity (ppt)	4.4	32.9	23.5	9.3	42
Temperature (°C)	26.2	33.0	29.0	2.0	42
Dissolved Oxygen (ml/L)	2.6	6.7	4.5	1.0	41
Dissolved Oxygen (% saturation)	58.7	133.5	97.0	17.8	41
pH	6.6	8.8	8.3	0.5	41
Chlorophyll *a* (mg m^{-3})	7.2	65.3	18.2	15.7	41
Primary Productiv. (mg C m^{-3} hr^{-1})	1.4	391.7	69.8	94.2	40
$N\text{-}NH_4$ (µg/L)	1.0	14.9	5.6	3.4	42
$N\text{-}NO_3+NO_2$ (µg/L)	0.7	13.3	3.0	3.5	42
Total N (µg/L)	3.7	21.7	10.6	4.7	42
NH_4/Total N	24.8	87.2	62.2	19.4	42
$P\text{-}PO_4$ (µg/L)	0.1	3.4	0.9	0.7	42
Total P (µg/L)	0.2	10.2	2.2	2.2	42
Organic P (µg/L)	0.1	9.9	1.5	2.0	42
N:P Ratio	3.6	42.8	8.9	7.1	36
Trophic index	49.9	96.1	59.2	8.3	42
C/Chl (mg C m^{-3} hr^{-1}/mg chl. m^{-3})	0.2	21.1	4.5	3.9	39

flexuosa, N. reclivata, M. lateralis and *Littoridina sphynctostoma* are noticeable for their relative value (Reguero and García-Cubas 1990, 1991). The list of anomura and brachiura in the lagoon includes *Clibanarius vittatus, Callinectes similis, Callinectes rathbunae, Callinectes sapidus, Eurypanopeus depressus, Hexapanopeus* sp., *Dyspanopeus texanus, Panopeus lacustris, Rhithropanopeus harrisii, C. guanhumi, Pachygrapsus gracilis, Sesarma (Holometopus) ricordi, Goniopsis cruentata, Aratus pisonii, Pinnotheres ostreum, Uca (Minuca) rapax rapax, U. vocator vocator* and *U. marguerita* (Raz-Guzmán *et al.* 1991). More than 100 species of fish have been identified, of which the following stand out: *D. maculatus, D. rhombeus* and *Cichlasoma urophthalmus,* while for the artificial mouth five species were the most abundant*Ulaema lefroyi, Evorthodus lyricus, G. boleosoma, D. maculatus* and *B. soporator* (Cruz and Rodríguez 1991, in Castañeda and Contreras 2001; Chávez and Franco 1992, in Castañeda and Contreras 2001). One hundred and fifty-four species of birds have been identified (Carmona *et al.* 1987, in Castañeda and Contreras 2001) and 18 species of other aquatic organisms. The presence of 13 pesticides has been detected, such as endosulfan II, endrin and aldrin among others. The hydrology of the Laguna Alvarado is presented in Table 12.10.

LAGUNA SONTECOMAPAN

A total of seven phanerogams were detected: *R. maritima, Najas guadalupensis, Pistia statiotes, Lemna* sp., *Potamogeton interruptus* and *Potamogeton foliosus*. With the exception of the first, the species only occur at certain times of the year. The ichthyoplankton was composed of 14 families, 17 genera and 16 species. The largest relative abundance corresponds to the family Gobiidae with 82.78%, followed by the Engraulidae with 12.37% and the Sciaenidae with 3.74%. A total of 60 species of molluscs was reported. The representative species regarding distribution and relative abundance are *N. reclivata, N. virginea, M. lateralis* and *M. leucophaeata* (García-Cubas and Reguero 1995). Sixty-eight species of fish have been identified, and the most common were *A. hepsetus, Cathorops aguadulce, G. hastatus* and *A. lineatus* (de la Cruz *et al.* 1985). Table 12.11 summarizes its hydrology.

LAGUNA DEL OSTIÓN

Seven species of crustaceans and 36 of fish have been identified, of which the following stand out: *B. patronus, Anchoa lamprotaenia, A. mitchilli, A. melanopus, C. parallelus, O. saurus, Lutjanus apodus, E. melanopterus, Eucinostomus gula, D. rhombeus, Archosargus probatocephalus, B. soporator* and *C. spilopterus* (García 1988). The lagoon’s location inside one of Mexico's most important oil industry areas resulted in a considerable change of its ecological characteristics. Its hydrology is presented in Table 12.12.

COATZACOALCOS ESTUARY

The estuary originates in the Sierra Atravesada, running westward and later turning north and then northeast, emptying into the Gulf of Mexico. It is navigable for 222 km. Its main tributaries are the Río Jaltepec, which comes down from the Sierra de los Mijes and joins it on the left side, and the Río Uxpanapa, which originates on the north slope of the Sierra Atravesada and joins it on the right side just before its mouth. Fifty-eight species of fish larvae from 91

Table 12.10. Hydrology of Laguna Alvarado, Veracruz.

Parameter	1984					1996				
	Min	Max	Mean	St. D.	n	Min	Max	Mean	St. D.	n
Salinity (ppt)	0.1	39.0	9.3	8.4	87	0.3	33.6	5.0	6.8	50
Temperature (°C)	22.5	33.0	29.5	2.1	88	25.0	33.0	27.6	2.1	51
Dissolved Oxygen (ml/L)	2.0	7.4	5.2	1.0	81	2.7	7.9	5.5	1.1	51
Dissolved Oxygen (% saturation)	38.2	159.9	103.0	20.7	81	51.9	147.0	107.9	20.8	51
pH	7.0	9.0	8.3	0.4	76	6.9	8.8	8.3	1.2	50
Chlorophyll *a* (mg m^{-3})	0.01	174.5	13.7	45.4	81	4.9	138.8	15.2	23.2	46
Primary Productiv. (mg C m^{-3} hr^{-1})	8.5	437.5	64.8	112.7	24	0.6	183.3	51.3	47.7	42
N-NH_4 (μg/L)	0.2	84.2	8.9	12.5	72	1.2	44.8	10.0	10.1	51
N-NO_3+NO_2 (μg/L)	0.3	61.7	1.8	10.7	80	0.5	20.1	5.2	4.1	51
Total N (μg/L)	0.3	123.2	13.9	20.8	80	4.9	45.8	15.6	10.0	51
NH_4/Total N	28.4	96.9	78.1	22.3	72	12.8	97.8	56.7	25.7	51
P-PO_4 (μg/L)	0.2	25.3	2.0	3.0	78	0.0	13.4	1.4	2.3	51
Total P (μg/L)	0.1	16.4	2.8	3.6	47	0.2	14.0	4.4	2.9	51
Organic P (μg/L)	0.0	7.0	1.4	1.5	23	0.0	7.2	2.9	1.9	51
N:P Ratio	0.2	45.5	6.6	10.7	73	0.9	35.2	8.3	9.6	42
Trophic index	32.0	81.2	56.5	13.7	76	46.2	83.5	57.7	7.7	47
C/Chl (mg C m^{-3} hr^{-1}/mg chl. m^{-3})	0.4	25.9	3.5	7.5	20	0.1	23.9	3.3	5.0	39

Table 12.11. Hydrology of Laguna Sontecomapan, Veracruz (1992).

Parameter	Min	Max	Mean	Stand. Dev.	n
Salinity (ppt)	0.3	37.8	12.3	12.5	36
Temperature (°C)	25.0	34.8	30.5	2.3	36
Dissolved Oxygen (ml/L)	3.5	8.5	6.0	1.2	36
Dissolved Oxygen (% saturation)	75.0	175.0	123.5	22.2	36
pH	6.8	8.7	8.0	0.4	36
Chlorophyll *a* (mg m^{-3})	0.1	50.4	13.0	15.0	28
Primary Productiv. (mg C m^{-3} hr^{-1})	1.1	409.1	106.8	109.9	13
N-NH_4 (μg/L)	1.8	32.7	6.9	8.0	35
N-NO_3+NO_2 (μg/L)	0.7	14.8	3.1	4.4	36
Total N (μg/L)	3.5	47.5	11.1	11.2	35
NH_4/Total N	29.1	91.6	71.8	15.8	35
P-PO_4 (μg/L)	1.0	5.3	2.3	1.3	36
Total P (μg/L)	1.9	9.3	3.9	1.6	36
Organic P (μg/L)	0.1	4.8	1.2	1.0	36
N:P Ratio	0.7	28.4	5.7	7.9	35
Trophic index	5.8	69.0	55.7	16.5	27
C/Chl (mg C m^{-3} hr^{-1}/mg chl. m^{-3})	0.3	5.9	3.2	1.9	10

Table 12.12. Hydrology of Laguna del Ostión, Veracruz (1985).

Parameter	Min	Max	Mean	Stand. Dev.	n
Salinity (ppt)	0.2	33.9	13.0	13.0	45
Temperature (°C)	20.5	30.8	28.3	3.7	45
Dissolved Oxygen (ml/L)	3.2	5.7	5.0	0.6	45
Dissolved Oxygen (% saturation)	58.5	121.8	99.7	14.9	45
pH	6.7	9.3	8.0	0.7	45
Chlorophyll *a* (mg m^{-3})	0.01	38.2	5.5	8.8	45
Primary Productiv. (mg C m^{-3} hr^{-1})	2.1	133.3	27.0	36.7	35
N-NH_4 (μg/L)	6.2	40.1	11.1	10.7	45
N-NO_3+NO_2 (μg/L)	0.2	13.7	1.5	3.1	45
Total N (μg/L)	1.5	43.3	12.5	11.5	45
NH_4/Total N	39.8	97.8	91.6	14.6	45
P-PO_4 (μg/L)	0.4	37.3	4.5	13.1	3
N:P Ratio	0.1	30.5	2.1	7.0	30
Trophic index	35.8	66.3	50.3	8.7	45
C/Chl (mg C m^{-3} hr^{-1}/mg chl. m^{-3})	0.2	17.7	1.8	5.3	30

genera and 58 families were identified (León 1990). Fifty-one species of crustaceans were identified, of which *Penaeus (Farfantepenaeus) aztecus* and the crab *Portunus spinicarpus* stood out. *Callinectes similis, G. lateralis, C. guanhumi* and *Ucides cordatus*, and 22 other aquatic organisms were identified in the coastal area (Bozada and Páez 1986a). Forty-six species of fish are reported, including: *Dorosoma anale*, *Ictalurus meridionalis*, *B. marinus, A. felis, A. melanopus, C. parallelus, Selene vomer, D. rhombeus, Stellifer lanceolatus, B. chrysoura, C. spilopterus, T. maculatus* and *A. lineatus*. The results of several investigations point out the importance of the Coatzacoalcos wetlands for resident and migratory birds (Herzig 1986). This region contains the greatest industrial concentration regarding the refining of hydrocarbons, production of petrochemicals and their transport along the Mexican coast of the Gulf of Mexico.

TONALÁ ESTUARY

The estuary is formed by the Tancochapa and Zanapa rivers. The former is formed by the merging of the Playas and Pedregal rivers, which originate in the Sierra Atravesada, and the latter, which runs from the east, is formed by Arroyo San Juan, the Río Costijapa and the waters of Laguna Rosario. The ichthyofauna of the Río Tonalá is represented by 50 species, and is typified by *A. melanopus, D. rhombeus* and *A. lineatus*, since they represent the greatest abundance of the total captured organisms. Also reported are *D. anale, B. marinus, A. felis, A. melanopus, C. parallelus, B. ronchus, C. faber, C. spilopterus, T. maculatus* and *Monacanthus hispidus*. Eight species of crustaceans, 202 of birds (Herzig 1986) and 22 of other aquatic organisms (Bozada and Páez 1986b) were reported. The estuary is navigable for 200 km.

LAGUNA DEL CARMEN MACHONA

Ninety-five species of molluscs have been identified (Antolí and García-Cubas 1985). The most abundant gastropods were *C. pliculosa, N. virginea*, *Crepidula plana*, *N. vibex* and *Nassarius acutus,* and most abundant bivalves were *R. flexuosa, Donax variabilis texasiana*, *Rangia cuneata*, *C. virginica* and *Ostrea equestris*. Eight species of crustaceans were captured, of which *C. similis*, *C. rathbunae*, *C. sapidus* and *P. setiferus* were the most abundant (Granados *et al.* 1991). With respect to the carcinological fauna, Urbina (1996) identified 13 families and 19 genera including 25 species, six of which are of commercial importance, three from the Portunidae family, *C. sapidus*, *C. rathbunae* and *C. similis*, and three from the Penaeidae family, *Penaeus duorarum, P. aztecus* and *P. setiferus*. The species with greatest abundance and broadest distribution was *C. vittatus*, which occurred in almost the whole system. It should be noted that two of the total species, *Heterocrypta granulata* and *Pinnixa cristata*, are of great interest because they represent the first records for the Gulf of Mexico and, therefore, for the state of Tabasco. Reséndez (1980) listed *Aetobatus marinari*, *Peprilus paru*, *Ophichthus pomesii*, *Callechelys perryae*, *Myrophis punctatus*, *A. hepsetus*, *M. curema* and *D. olisthostomus* as the most common species of fish. Years later, in order to assess the impact caused by the significant widening of the Barra de Alacranes on the composition of the ichthyofauna in this area, a study was carried out over an annual cycle. To this date 54 species of 43 genera and 28 families were observed, of which only 40 species coincide with the previous ones. Among the species observed by Reséndez (1980) but not captured, inhabitants of less saline waters, such as *Gambusia yucatána*, *C. urophthalmus* and *G. boleosoma*, among others, should be pointed out (Granados *et al.* 1991). The hydrology of this lagoon is presented in Table 12.13.

LAGUNA TUPILCO

This lagoon is the habitat of 62 species of molluscs, among which *M. leucophaeata*, *R. flexuosa, A. canaliculata* and *L. sphinctostoma* stand out for their abundance, frequency and relative density (García-Cubas and Reguero 1990). The lagoon's hydrology is summarized in Table 12.14.

LAGUNA DE MECOACÁN.

Forty-two species of molluscs, 20 corresponding to the class Gastropoda and 22 to the Bivalvia occur here. The most important are *L. sphinctostoma, A. canaliculata, Odostomia impressa, M. leucophaeata, R. flexuosa* and *M. lateralis* (García-Cubas *et al.* 1990b). Granados (1992) states that 26 species of crustaceans were observed, including: *C. similis*, *C. sapidus*, *C. rathbunae*, *C. vittatus* and *P. setiferus*. Forty-nine species of fish were identified, of which the most important were *D. rhombeus*, *E. gula*, *A. melanopus*, *D. auratus*, *A. haspsetus*, *L. griseus* and *B. ronchus* (Granados *et al.* 1991). Table 12.15 summarizes its hydrology.

CENTLA MARSHES

The marshes represent an important Biosphere Reserve and Ramsar Site, with a total extension of 302,706 hA. It is predominantly a fluvio-deltaic plain with aquatic systems that occupy extensive depressions between fluvial plains. Its characteristics include accumulation of

Table 12.13. Hydrology of Laguna Carmen-Machona, Tabasco (1985).

Parameter	Min	Max	Mean	Stand. Dev.	n
Salinity (ppt)	27.2	35.0	32.6	2.5	17
Temperature (°C)	26.1	29.9	28.9	0.8	17
Dissolved Oxygen (ml/L)	3.2	5.3	4.5	0.5	16
Dissolved Oxygen (% saturation)	69.9	117.7	99.8	10.6	16
Chlorophyll *a* (mg m^{-3})	6.2	135.9	14.0	32.1	15
Primary Productiv. (mg C m^{-3} hr^{-1})	8.3	239.9	59.3	67.3	12
N-NH_4 (µg/L)	1.3	13.4	3.7	4.1	17
N-NO_3+NO2 (µg/L)	0.5	2.3	1.2	0.5	15
Total N (µg/L)	2.3	14.6	4.3	4.1	17
NH_4/Total N	42.1	100.0	83.2	18.5	17
P-PO_4 (µg/L)	0.8	10.3	3.4	2.6	17
Total P (µg/L)	2.4	21.6	6.3	4.5	17
Organic P (µg/L)	0.3	12.4	1.8	3.2	17
N:P Ratio	0.3	7.1	1.6	2.1	17
Trophic index	48.5	78.8	56.5	7.7	15
C/Chl (mg C m^{-3} hr^{-1}/mg chl. m^{-3})	0.4	14.8	4.0	5.0	12

Table 12.14. Hydrology of Laguna Tupilco, Tabasco (1987).

Parameter	Min	Max	Mean	Stand. Dev.	n
Salinity (ppt)	8.9	41.2	17.7	11.9	12
Temperature (°C)	30.5	36.6	32.7	1.9	12
Dissolved Oxygen (ml/L)	1.6	4.6	3.9	1.0	12
Dissolved Oxygen (% saturation)	38.0	106.0	89.0	21.0	12
pH	7.1	7.8	7.5	0.3	6
Chlorophyll *a* (mg m^{-3})	2.1	35.6	10.7	13.0	12
Primary Productiv. (mg C m^{-3} hr^{-1})	21.9	469.1	96.9	176.0	5
N-NH_4 (µg/L)	2.7	22.2	5.5	5.9	11
N-NO_3+NO_2 (µg/L)	0.6	2.6	0.9	0.6	12
Total N (µg/L)	3.4	83.0	6.8	22.1	12
NH_4/Total N	56.1	98.3	86.9	11.1	12
P-PO_4 (µg/L)	6.3	19.0	14.3	3.4	12
Total P (µg/L)	8.1	22.1	14.8	4.1	9
Organic P (µg/L)	0.1	3.4	1.9	1.3	7
N:P Ratio	0.3	7.0	0.6	1.9	12
Trophic index	37.8	65.6	53.3	9.9	12
C/Chl (mg C m^{-3} hr^{-1}/mg chl. m^{-3})	4.0	20.5	10.5	6.5	5

Table 12.15. Hydrology of Laguna Mecoacán, Tabasco (1985)

Parameter	Min	Max	**Mean**	Stand. Dev.	n
Salinity (ppt)	22.3	34.0	**31.8**	5.3	6
Temperature (°C)	26.2	29.0	**27.8**	1.2	6
Dissolved Oxygen (ml/L)	4.1	4.5	**4.2**	0.2	6
Dissolved Oxygen (% saturation)	88.6	97.5	**91.8**	3.7	6
Chlorophyll *a* (mg m^{-3})	0.9	4.6	**2.3**	1.3	6
Primary Productiv. (mg C m^{-3} hr^{-1})	3.1	105.2	**49.0**	44.5	4
N-NH_4 (µg/L)	4.4	10.3	**5.3**	2.6	6
N-NO_3+NO_2 (µg/L)	0.5	1.7	**1.1**	0.4	5
Total N (µg/L)	4.4	11.4	**6.7**	2.6	6
NH_4/Total N	75.1	100.0	**86.6**	9.7	6
P-PO_4 (µg/L)	1.1	3.2	**2.5**	0.8	6
Total P (µg/L)	2.4	3.8	**3.3**	0.5	6
Organic P (µg/L)	0.2	1.7	**0.6**	0.6	6
N:P Ratio	1.5	5.4	**3.3**	1.6	6
Trophic index	29.5	45.5	**38.8**	5.7	6
C/Chl (mg C m^{-3} hr^{-1}/mg chl. m^{-3})	3.5	29.3	**22.2**	11.1	4

permanent water, shallow depth, irregular edges, fine sediments of alluvial origin, accumulation of organic layers ranging from a few centimeters to more than 1 m thickness without accumulation of salts of marine origin and with several communities of emerging hydrophytes. According to several sources at least 52 species of fish, 68 of reptiles, 27 of amphibians, 104 of mammals and 255 of birds have been reported (Castañeda and Contreras 2001).

LAGUNA DE TÉRMINOS

The lagoon is located in the transition area between the limestone of the Yucatán Peninsula and the alluvial terrain of the Gulf of Mexico. A total of 173 species of molluscs have been identified, among which gastropods stand out for their abundance and widespread distribution (95), among which *D. varium*, *Turbonilla (Chemitzia) aequalis*, *A. canaliculata*, *Rissoina catesbyana*, *Caecum (Micranellum) pulchellum*, *Mitrella (Astyris) lunata*, *Triphora melanura*, *Melanella (Balcis) conoidea* and *Vitrinella multistriata* are dominant in number and frequency. Among the bivalves *Nuculana (Sacella) acuta, M. lateralis*, *L. mortoni*, *Corbula (Caryocorbula) contracta*, *Anadara (Lunarca) ovalis*, *Abra aequalis*, *Anadara (Larkinia) transversa*, *Macoma (Austromacoma) constricta*, *Macoma (Rexithaerus) mitchelli* and *Brachiodontes (Hormomya) exustus* predominate (García-Cubas 1981). It is relevant to mention the benthic macrofauna associated with the seagrass beds of *Thalassia testudinum*, where 123 species of polychaetes, 57 of molluscs and 68 of crustaceans were identified (Reveles and Escobar 1987). Polychaetes were the dominant group. *Capitella capitata*, *M. californiensis*, *Laeonereis culveri*, *Streblospio benedicti*, *Lembos sp.*, *Lucina pectinata*, *Palaemonetes vulgaris*, *Melinna maculata*, *Tellina lineata*, *Xenanthura sp.*, *Tellina alternata tayloriana* and *Parandalia*

vivianneae were the most abundant species (Hernández and Solís 1995). There are five permanent resident species in the fish communities: *Orthopristis chrysopterus, H. plumieri, Archosargus rhomboidalis, Corvula sanctae-luciae* and *Sphoeroides testudineus*. One hundred and fifty species have been detected (Yañez-Arancibia and Zarate 1999). Ayala *et al.* (2000, in Castañeda and Contreras 2001) reported 107 species, 18 of which are considered dominant: *A. melanopus, D. rhombeus, E. gula, B. chrysoura, A. rhomboidalis, B. marinus, Cetengraulis edentulus, Eugerres plumieri, A. felis, S. lanceolatus, Chloros combrus chrysurus, A. mitchilli, Cynoscion arenarius, Chaetodipterus faber, B. ronchus, Sphoeroides nephelus, Dasyatis sabina* and *Himantura schmardae*. One hundred and thirty-eight species of birds are reported (Rico-Gray *et al.* 1988). The only complete hydrological information comes from Botello (1978), and is presented in Table 12.16.

LAGUNA CELESTÚN

The subaquatic vegetation is composed of 28 species, mainly the algae *Chara fibrosa, Bathophora oerstedi* and *Chaetomorpha linun* in the northern part. In the central and southern part, the most notable species are *Halodule wrightii, Syringodium filiforme, Ruppia cirrhosa* and the alga *C. linum*, which are found at the edges of the lagoon, forming dense carpets (Herrera 1988). Near the mouth and in coastal waters the dominant seagrass is *T. testudinum*. It should be pointed out that macroalgae are dominant (> 70% of the biomass) over seagrasses. Gastropods were represented by 20 species grouped in 17 genera and 14 families, and bivalves by 13 species in 11 genera and 7 families (Lizárraga and Ardisson 1995). There are 41 species in the ichthyofauna: *E. gula, E. argenteus, A. rhomboidalis, S. testudineus, Serranus atrobronchus, Sparisoma radians, L. griseus, Monocanthus hispidus, Chloroscombrus chrysurus, C. hippos, Chilomycterus schaeffi, Syngnatus lousianae, Orthopristis chrysoptera, A. melanopus* and *L. rhomboides* (Mena and de la Cruz 1993). Three hundred and four species of birds have been recorded from 179 genera, 45 families and 20 orders. The lagoon is considered to be an important habitat both for resident and migratory birds. *Phalacrocorax olivaceus* and *Dendrocygna autumnalis* are among the nesting birds (Correa and García 1993). Other common species are *Anas discors, Anas acuta, Anas carolinenesis, Anas cyanoptera, Aythia affinis, Aythia collaris, Nareca americana, Spatula clypeata, Fulica americana, Bucephala alveola, Oxyura jamaicensis, Mergus serrator, Cairina moschata* and *Aix sponsa*. The hydrology comes from Batllori (1988) and is summarized in Table 12.17.

YUCALPETÉN

Organisms from seven phyla, 12 classes, 29 orders, 37 families, 61 genera and 60 species were identified among the macrobenthic fauna inhabiting the seagrass beds of *T. testudinum*. The fauna observed in these seagrass beds in very abundant and diverse and is represented mainly by the phylum Arthropoda, followed in abundance by the Echinodermata, Mollusca, Vertebrata and Annelida. Organisms of the phyla Nematoda and Cnidaria are the scarcest. Important species are *Cladonema radiatum, Sabella microphtalma, Cerithidea costata* and *Crepidula maculosa* (Hernández and May 1990).

Table 12.16. Hydrology of the Laguna de Términos, Campeche (1974).

Parameter	Min	Max	Mean	Stand. Dev.	n
Salinity (ppt)	27.7	33.5	30.1	2.4	95
Temperature (°C)	27.4	29.4	29.0	0.9	95
Dissolved Oxygen (ml/L)	4.6	5.0	4.7	0.2	95
Dissolved Oxygen (% saturation)	96.0	105.0	97.5	4.2	95
pH	8.2	8.3	8.2	0.0	95
$N\text{-}NH_4$ (μg/L)	4.3	25.7	5.2	10.4	95
$N\text{-}NO_3+NO_2$ (μg/L)	0.1	1.4	0.2	0.6	95
Total N (μg/L)	5.3	25.9	5.6	10.2	95
NH_4/Total N	76.0	99.0	95.5	10.5	95
$P\text{-}PO_4$ (μg/L)	0.3	0.7	0.5	0.2	95
N:P Ratio	8.4	16.5	10.2	4.2	95

Table 12.17. Hydrology of Laguna Celestún, Yucatán (1985).

Parameter	Min	Max	Mean	Stand. Dev.	n
Salinity (ppt)	5.5	32.0	16.5	7.6	17
Temperature (°C)	23.0	30.2	27.9	2.3	17
Dissolved Oxygen (% saturation)	44.0	139.0	95.0	27.5	17
Chlorophyll *a* (mg m^{-3})	1.1	56.2	2.3	14.8	15
Primary Productiv. (mg C m^{-3} hr^{-1})	14.8	338.0	121.0	99.4	11
$N\text{-}NH_4$ (μg/L)	3.0	10.2	5.1	2.1	15
$N\text{-}NO_3+NO_2$ (μg/L)	1.8	9.8	3.5	2.5	15
Total N (μg/L)	2.3	18.4	9.8	3.6	15
NH_4/Total N	30.0	77.6	56.9	15.6	14
$P\text{-}PO_4$ (μg/L)	0.3	7.1	2.7	1.9	14
N:P Ratio	1.3	26.4	4.6	7.7	14
Trophic index	33.1	70.1	39.3	12.0	14
C/Chl (mg C m^{-3} hr^{-1}/mg chl. m^{-3})	5.1	49.7	13.3	19.4	6

DZILÁM DE BRAVO

This is a state natural protected area and it presents a strip of marshes covering about 20 km and including the marshes of El Paso, Yolbe and El Islote. *Ruppia maritima* and *Halodule wrightii* cover 90% of the bottom. The main algae are *Bryothamnium seafortii*, *Chaetomorpha linum*, *B. oerstedi* and *Polysiphonia* sp. Thirty-one species of fish have been recorded, among which *L. rhomboides*, *E. gula*, *Sphoeroides testudinus*, *E. argenteus*, *O. chrysoptera* and *Sphyraena barracuda* predominate (Chumba and Barrientos 2000, in Castañeda and Contreras 2001).

RÍA LAGARTOS

This is a Biosphere Reserve and a Ramsar Site. The system is divided in three parts: the first extends from of the mouth of the San Felipe to the mouth of the channel; the second extends

from the evaporation ponds of the salt pits to the Straits; and the third from the Straits to the eastern end of the marsh. A phycofloristic study identified a total of 46 taxa, including 26 species of the division Rhodophyta, 18 of Chlorophyta and 2 of Phaeophyta (Ortegón *et al.* 2001). Among the benthos there are *C. pliculosa, A. auberiana*, *Tellina tampaensis*, *Carditamera floridana* and *Limulus polyphemus*. From the commercial perspective, the presence of *Panulirus argus*, *Octopus maya*, *Octopus vulgaris* and *P. aztecus* is notable. Eighty-four species of marine megabenthic invertebrates were identified in the reserve, of which eight were porifera (2 encrusting sponges, 2 branching sponges and 4 massive sponges), 11 cnidaria (3 massive hexacorals, 3 branching hexacorals, 4 octocorals and 1 anemone), 49 molluscs (25 gastropods, 22 bivalves, 1 cephalopod, 1 opistobranchia), 6 crustaceans and 9 echinoderms (4 starfish, 2 sand dollars, 2 sea urchins and 1 sea cucumber) (Maldonado *et al.* 2000). There are 49 species in the ichthyofauna (69 according to Vega *et al.* 1998), 40 genera and 30 families. The most abundant species were *Floridichthys carpio*, *E. argenteus*, *S. notata*, *S. testudineus* and *Elops saurus* (de la Cruz and Mena 1997, in Castañeda and Contreras 2001).

THE DATABASE

The Laboratorio de Ecosistemas Costeros (Coastal Ecosystems Laboratory) of the Universidad Autónoma Metropolitana (UAM) Iztapalapa began its sampling activities in coastal lagoons in 1979, and to date annual cycles of basic hydrological sampling have been carried out in 41 ecosystems throughout the country (17 on the Gulf and 24 on the Pacific).

In the case of the Gulf of Mexico and based on information from 19 different lagoon systems and, in some cases, with cycles conducted in different years, as with the Tampamachoco, La Mancha, Tamiahua and Mandinga lagoons (some of these cycles are presented in the previous lagoon diagnostics), a data matrix was prepared. The summarized data matrix for the Gulf of Mexico with its minimum, maximum, average and total number of data (n) for each parameter is shown in Table 12.18.

The data matrix below allows us to obtain an average value for each characteristic and thus approximate the “normal” value for the lagoons. In addition, the mean values for each of the abiotic parameters and for each coastal lagoon favor an approach for classification purposes, since these results permit us to know the trends of each ecosystem regarding any particular characteristic. For example, the mean salinity for the Laguna Madre is 41.2 ppt and reflects the tendency toward hypersalinity, compared to the mean of 9.3 ppt for the Laguna Alvarado, which indicates the permanence of oligohaline conditions. In both cases there are considerable variations associated with climate temporality (rains and drought), but final tendencies towards a characteristic value are maintained. In this manner the analysis of the data for other characteristics, such as phosphates or chlorophyll, would show tendencies to oligotrophy or, on the contrary, to eutrophication.

HYDROLOGICAL CHARACTERISTICS

The coastal ecosystems of the Gulf of Mexico reflect values that are considered normal for estuarine areas. Thus, the average salinity of 22.9 ppt shows the permanence of the estuarine character as a fundamental feature; high salinities correspond mainly to the Laguna Madre. The mean dissolved oxygen data reflects waters with a high quantity of the gas (5 ml/L); the variation

Table 12.18. Summary of the data matrix of the Gulf of Mexico.

Parameter	Min	Max	Mean	Stand. Dev.	n
Salinity (ppt)	0.00	63.0	22.6	12.2	933
Temperature (°C)	14.6	36.8	28.7	5.1	990
Dissolved Oxygen (ml/L)	0.3	12.7	5.0	1.7	915
Dissolved Oxygen (% saturation)	6.6	235.0	101.1	37.6	868
pH	5.1	9.5	8.1	2.7	709
Chlorophyll *a* (mg m^{-3})	0.01	174.5	9.5	21.7	759
Primary Productiv. (mg C m^{-3} hr^{-1})	0.4	603.1	64.3	100.8	416
N-NH_4 (μg/L)	0.04	39.4	6.2	6.7	904
N-NO_3+NO_2 (μg/L)	0.05	55.6	2.1	5.5	929
Total N (μg/L)	0.1	75.6	9.0	9.5	913
NH_4/Total N	1.3	100.0	75.4	24.3	891
P-PO_4 (μg/L)	0.01	37.3	2.0	5.3	906
Total P (μg/L)	0.1	99.6	3.7	7.7	630
Organic P (μg/L)	0.00	63.1	1.5	5.0	574
N:P Ratio	0.02	42.8	4.0	8.0	831
Trophic index	1.2	81.2	53.2	12.8	726
C/Chl (mg C m^{-3} hr^{-1}/mg chl. m^{-3})	0.04	39.8	4.3	7.7	299

in pH (with an average of 8.11) is caused by seasonal changes, since values near 7.0 are associated with continental water from rivers and rains, unlike sea water, with average values of 8.2. The homogeneity of these two parameters should be pointed out, with standard deviations of 1.7 and 2.7, respectively.

NUTRIENTS

Although many investigators have insisted on the wide variation of nutrients in coastal lagoons and similar ecosystems, it is interesting to observe that, based on the quantity of data collected and their standard deviation, they are not as variable as might be expected, despite the minimum and maximum values which, mainly in the case of nitrogen sources, are contrasting. This particularity could indicate that these extreme values are occasional and related to certain times and spaces only, rather than permanent.

The main form of nitrogen is N-NH_4, which constitutes a reduced form related to reducing conditions (low oxygen and pH values). It is considered to be indicative of renovated, used or anthropogenic nitrogen, since its presence increases with the increased use of adjacent lands for livestock as opposed to crops (Paerl *et al.* 2002). This is inferred by calculating the percent of NH_4/Total N, which averages 76%.

However, in coastal areas it is not as much their presence as the ratio between nutrients that is relevant (Redfield 1958; Redfield *et al.* 1963). Thus, an N:P ratio <5 is interpreted as a limitation of nitrogen, N:P >10 is considered to be indicative of phosphorus limitation, and N:P between 5 and 10 is established as indifferent (Rinaldi *et al.* 1992). The N:P ratio in the coastal ecosystems of the Gulf of Mexico tends to be low (4.0), i.e., it indicates a relative limitation of

nitrogenated forms. It should be pointed out that high N:P values (>10) are usually found in ecosystems associated with the predominance of sea water over fresh water contributions.

PRIMARY PRODUCTIVITY

Primary productivity constitutes the fundamental process of aquatic systems. In the case of tropical coastal lagoons, this process is composed of several basic components: phytoplankton (Grindley 1981; Boynton *et al.* 1982; Knoppers 1994; Cloern 1996), microphytobenthos (Hargrave and Conolly 1978; Webster *et al.* 2002), seagrasses (Zieman 1982; Ibarra and Ríos 1993; Kaldy *et al.* 2002), macrophyte vegetation (den Hartog 1982; Moreno-Casasola *et al.* 2001), chemosynthesis (Odum and Heald 1975; Klump and Martens 1981) and possibly macroalgae (Dreckmann and Pérez 1994). However, the quantification of the phytoplankton primary production is still a fundamental parameter in the interpretation of the health of an aquatic system.

On the other hand, the presence of chlorophyll *a* in the water has been used as an index of phytoplankton biomass and is measured routinely in studies related to primary productivity in the water column (Contreras 1994). Although there is not a directly proportional relationship between these two elements due, among other causes, to the physiological state of the phytoplankton, the particular succession moment, environmental variability, and the proportional and significant presence of very small forms such as nanophytoplankton (<22 µm), everything seems to indicate a great photosynthetic efficiency (Malone 1971; McCarthy *et al.* 1974). However, chlorophyll *a* is related to the quantity of nutrients, especially phosphates (Vollenweider and Kerekes 1982; Contreras and Kerekes 1992). In fact, a trophic classification has been established based on these two characteristics (Carlson 1977; Contreras *et al.* 1994). This conceptualization of cause and effect has been used to detect problems of eutrophication, since this phenomenon is primarily a response of the algal biomass to additional inputs of nutrients (Giovanardi and Tromellini 1992).

In the data matrix, the heterogeneity of the primary productivity in the water column stands out. In fact, the standard deviation calculated routinely for each system is always high, generally above 100, even in small systems. This indicates the extreme particularity of this process both temporally and spatially. From this perspective the behavior of chlorophyll *a* stands out, since it does not follow the same pattern regarding the heterogeneity of the primary productivity and is, at least in theory, a fundamental causative factor of this process.

In spite of these differences, the carbon/chlorophyll (C/Chl; mg C m^{-3} hr^{-1}/mg chl m^{-3}) ratio has been used as an index of photosynthetic potential (Beerman and Pollingher 1974). It could be considered a measure of the ecological efficiency of the phytoplankton (Strickland 1960; Cloern 1996; Banse 1974, 1977) since a high value means an optimization of the abiotic conditions for the development of primary producers. However, low values would be related to several limitations such as nutrients, light or some other factor. The monitoring of this ratio among the data generated in a single system offers useful information which is the key to some aspects. Although there is a great quantity of C/Chl data in Mexico, it is local and incidental, and dispersed throughout many research studies. Millán and Lara-Lara (1995), in an excellent collection of information on primary productivity, present C/Chl values for 20 Mexican coastal lagoons, some obtained from Gilmartin and Relevante (1978).

The data matrix gives 242 determinations of the C/Chl ratio and the values are very similar to those reported by the referred authors. Both the average and standard deviation values

are acceptable, given that this is such a variable ratio and dependent on other determinations. In terms of seasonality the highest values are associated with spring, when abiotic conditions are favorable to optimum development of phytoplankton forms such as diatoms. Spatially they are related to areas within the lagoon system with quicker and more efficient renewal times, as opposed to the lower values that are usually associated with isolated areas with slow water exchange.

Finally, the information presented here offers, for the first time, a statistical approach to the understanding of the fundamental role played by some parameters which until now were considered unreliable and very relative regarding the ecological character of coastal lagoons. Obviously, a great quantity of information is necessary for a more reliable approach and to establish a possible classification or hierarchization of the estuarine ecosystems in Mexico, but the first step to achieve this objective is proposed here.

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